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RECENT DEVELOPMENTS IN FUEL SUPPLY AND DEMAND

BY

ARNO C. FIELDNER

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

RECENT DEVELOPMENTS IN FUEL SUPPLY AND DEMAND[1]

By Arno C. Fieldner[2]

Six years ago, I addressed the annual meeting of the American Society for Testing Materials on "Fuels of Today and Tomorrow."[3] Since then, our country has been drawn into another great war of veritably global extent, with unprecedented demands on fuels, foods, and materials in general. My purpose in this address is to review the changes in fuel supply and demand since 1937 and to give you my views on the outlook for the future.

CONDITIONS IN 1937

During 1936 the United States produced and consumed one-third of the world production of coal, two-thirds of the petroleum, and about 95 percent of the natural gas. Two-thirds of the oil produced in all countries since the discovery well was drilled in 1859 had come from American wells. With the exception of the three depression years 1931, 1932, and 1933, new oil reserves were being discovered since 1924 well in excess of our increasing rate of consumption. Discoveries of natural gas, likewise, were tremendous in volume, and this fuel was being transported to most parts of the country by pipe lines, some of them more than 1,000 miles long. We had all kinds of mineral fuels in abundance and at prices that did not stint anyone in the maximum utilization of the mechanical devices that were being developed on every hand. No one suspected that the time might come in a few years when gasoline would be doled out to some of us at the rate of 1-1/2 gallons a week or that many of our fuel-oil furnaces would have to be converted to burn coal. Of course, these restrictions are due to unusual war conditions, such as lack of coastwise tanker transportation, unprecedented demand for aviation gasoline, and the shortage of rubber for automotive tires. However, these shortages do call our attention to the vital part of petroleum reserves in our country's future position among nations. Therefore, it is of special interest to review briefly the relations of recent supply and demand with respect to our various mineral fuels.

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[1] Address at a meeting of the Western Society of Engineers, Chicago, Ill., April 22, 1943; published in the Journal of the Western Society of Engineers, September 1943.

[2] Chief, Fuels and Explosives Service, Bureau of Mines, Washington, D. C.

[3] Fieldner, A. C., Fuels of Today and Tomorrow: Proc. Am. Soc. Test. Mat., vol. 37, pt. I, June 1937, pp. 31-53, incl.

As shown in figure 1, anthracite and bituminous coal supplied 90 percent of the mineral fuel and water-power energy of the United States in 1900. The effect of petroleum on the demand for coal was not noticeable, owing to the accelerating industrial activity created by the First World War and to the fact that during this period automobiles were stimulating new conceptions of transportation and were displacing horses, rather than trains and trolley cars, which received their energy from coal.

After the war, the displacing effect, first of petroleum, then of natural gas, caused a decline in the proportion of energy from coal until 1938, when it reached a minimum of 43 percent. Since that date the proportion has increased each year, reaching 49 percent in 1941. The proportion of energy from petroleum increased to a maximum of 35 percent in 1938 and has declined each year since that date to about 31 percent in 1941. Energy from anthracite has declined in general from 20 percent in 1900 to 5.8 percent in 1937 and has remained at about this figure since that date. The marked rise in production of natural gas began in 1922 and has continued at a slower rate since 1930. The maximum proportion was 11.6 percent in 1939. To calculate the proportion of coal displaced by water power, the fuel equivalent of water power is taken at the prevailing average of all central stations for each year, declining from 7.05 pounds per kilowatt-hour in 1899 to 1.84 pound in 1941. It is apparent from the horizontal trend of the water-power curve that the increase in water-power installations has been compensated by the increased efficiency of utilization of coal in central electric stations, and thus no appreciable increase in the proportion of the coal equivalent of water power resulted.

Now let us turn to figure 2, which illustrates the annual supply of energy of the United States. The population has increased, in an approximately straight line, from 77 million in 1900 to 133 million in 1941. The total supply of energy increased at a greater rate up to 1918 and then at about the same rate until 1929. The industrial depression then caused a sharp drop from 25,500 trillion B.t.u. to 16,800 trillion in 1932. With one interruption in 1938, the supply of energy then increased sharply to 27,300 trillion B.t.u. in 1941, our maximum all-time supply.

During the early part of this period, the production of bituminous coal increased at an average rate of 20 million tons per annum, reaching a maximum of 579 million tons (15,180 trillion B.t.u.) in 1918. That was the end of the rise; from that date the demand for bituminous coal wavered with the ups and downs of industrial activity until 1927, when there began a decline that ended at 310 million tons (8,114 trillion B.t.u.) in 1932. Except for 1938, the rate of production of coal increased rapidly each year to 511 million tons (14,500 trillion B.t.u.), in 1941. Preliminary figures for 1942 indicate a total production of 580 million tons of bituminous coal and lignite. This figure, also, is an all-time high, being 1 million tons higher than the previous maximum of 579 million tons in 1918. Thus we have another wartime maximum production.

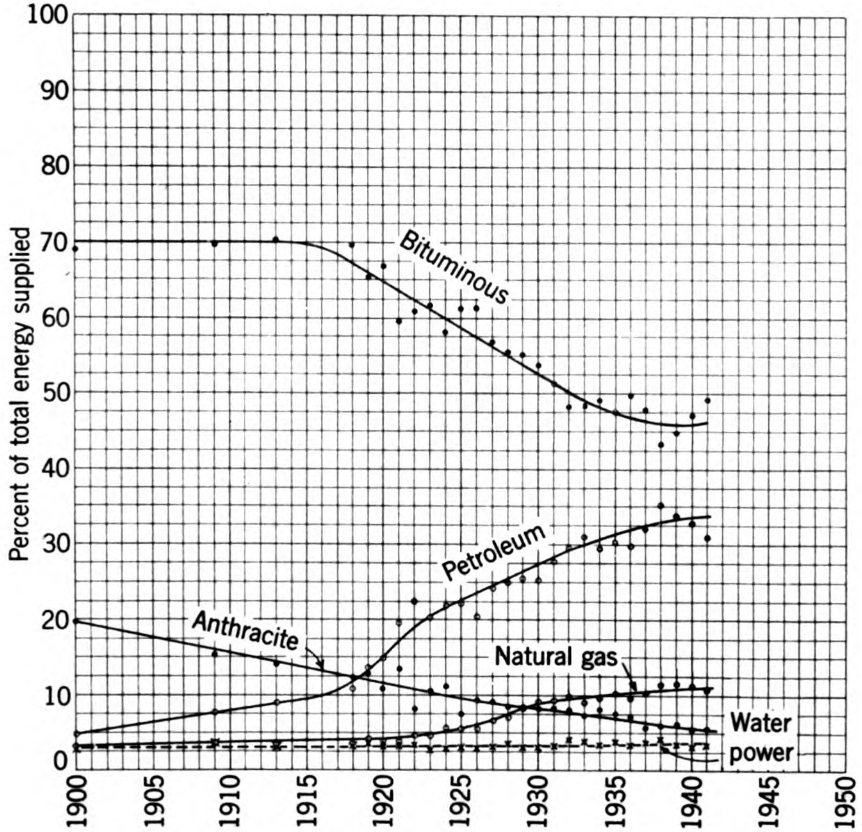

Figure I.- Percentage of total energy supplied by mineral fuels and water power.

Data from Bituminous Coal and Lignite, Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, p. 13. Fuel equivalent of water power is taken at prevailing average of all central stations for each year, declining from 7.95 lb. per kw.-hr. in 1899 to 1.34 lb. in 1941.

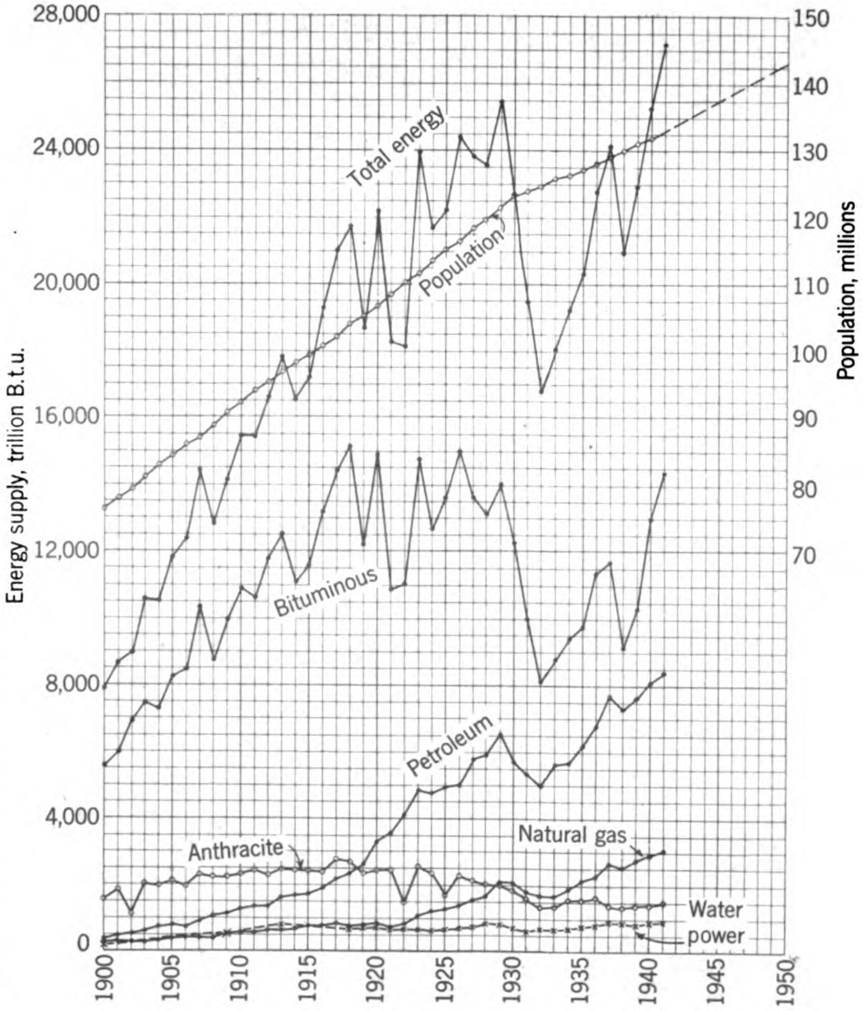

Figure 2.- Annual supply of energy from mineral fuels and water power in the United States, 1900-41, in trillions of B.t.u.

Data from Bituminous Coal and Lignite, Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, p. 12.

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CAUSE OF DECLINE IN USE OF COAL

The decline of the proportional consumption of anthracite and bituminous coal coincident with the rise in the proportion of energy from petroleum and natural gas, as shown in figure 1, indicates that these fuels displaced coal to a large degree. In addition, there was a marked and gowing increase of efficiency in the utilization of coal.

RISE IN USE OF PETROLEUM

The invention of the internal-combustion engine and the increased use of automotive transportation that it engendered have been the outstanding developments of the mechanical age in our country. The number of motor vehicles in the United States has increased from 9 million in 1920 to 27 million in 1929 and to 35 million in 1941. No figures on the rate of increase of airplanes are included, but obviously the tremendous growth of military aviation will accelerate the development of civil aviation on a world-wide scale after the war. This vast increase of automotive horsepower has required a constantly increasing production of petroleum to supply the necessary lubricants and fuel. To supply these needs, the production of gasoline has been increased from 122 million barrels in 1920 to 671 million barrels in 1941. Up to the present war condition, the oil industry has been able to meet all demands for liquid fuel, although failure to increase the rate of oil production between 1923 and 1926 caused a shortage and led to consideration of the possibility of producing supplemental motor fuels from oil shale, coal, and vegetable materials. However, this fear of a shortage soon was allayed. Deeper drilling - to depths of 7,000 feet, then to 10,000 feet, and more - and the use of geophysical methods for finding oil-bearing strata provided new discoveries at an increasing rate; in addition, the enormous East Texas pool, having an area of some 200 square miles, was discovered in 1930 by wildcat methods. Oil production increased from 771 million barrels in 1926 to 1,404 million in 1941.

Parallel with the finding of new sources of crude oil, there was continued progress in increasing the yield and quality of the gasoline produced. As geologists and physicists helped prospectors to find more oil, so chemists and engineers aided refiners in making more and better gasoline from the crude oil and from the vapors - formerly wasted - that are associated with the oil.

The application of heat and pressure to breaking down of the complex molecules of crude oil to the simpler ones of gasoline, accomplished commercially by Burton in 1912, started a series of improvements in refining that have increased the production ratio of gasoline to crude oil from 13 percent in 1912 to 45 percent in 1939. Today some refineries are obtaining a 70-percent yield of gasoline. A second far-reaching development was the discovery in 1922, by Midgley and Boyd (inspired by Kettering), that the addition of small quantities of tetra-ethyl lead and certain other substances to gasoline would suppress detonation and permit the use of higher compression ratios in the engine and higher compression increased the number of miles obtainable from a gallon of gasoline. This development by automotive engineers induced, in turn, new research by petroleum chemists in rearranging the molecular construction of both gaseous and liquid hydrocarbons so as to produce fuels that permit still higher compression ratios, such as the 100-octane aviation fuel being used by our air forces on the fighting fronts today. By chemical modification and addition of tetra-ethyl lead, the antiknock properties of gasoline have been improved from an average octane rating of 59 for regular-grade gasoline in 1930 to 70 in 1936 and to 75 in 1941. Premium grades rated 80 and aviation grades up to 100 and more. War needs for aviation gasoline and butadiene probably have stopped temporarily the upward octane trend of motor gasoline. After the war, the large capacity for 100-octane aviation gasoline probably will lead to the use of higher-compression automobile engines, with resulting greater fuel economy; such fuel saving will be needed if the decline in discovery of new oil reserves is not arrested. The average compression ratio of automobile engines sold in 1925 was 4.1:1. With the general increase in the octane number of motor fuel sold, the average compression ratio was increased to 6.1 in 1936 and to 6.7 in 1941.

Much of the recent improvement in the antiknock properties of gasoline has been accomplished by utilizing the volatile liquid hydrocarbons in natural gas and still gases formerly used as refinery fuel. Here chemists reversed the cracking process of breaking down the large molecule of heavy oil into smaller gasoline molecules. Polymerization consists of building up molecules of gasoline size by uniting gaseous and light-vapor molecules, such as the unsaturates ethylene, propylene, and butylene, present in large proportion in cracking-still gases and the saturated hydrocarbons ethane, propane, and butane. The catalytic and thermal polymerization processes began operating on a commercial scale in 1935 and expanded with the increasing demand for high-octane aviation fuel. About 1939 another building-up process, known as "alkylation," attained commercial development and in recent years has supplanted the polymerization process to a considerable degree because of lower investment and operating costs. In the polymerization process, 2 molecules of the paraffin series are united to produce 1 unsaturated molecule, which must be hydrogenated to obtain iso-octane. In the alkylation process, 1 molecule of the paraffin series is united with 1 molecule of the olefin series to produce a saturated molecule of high-octane value, as, for example, the union of isobutane (C_4H_{10}) and butylene (C_4H_8) to form iso-octane. Both processes are being used almost entirely for the production of high-octane aviation fuel.[4]

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[4] White, A. G., Hopkins, G. R., and Breakey, H. A., Crude Petroleum and Petroleum Products: Bureau of Mines Minerals Yearbook 1940, Review of 1939, p. 991.

Still more recent developments in the accelerating pace of rearranging the chemical elements of the hydrocarbon molecule into a more powerful form are the "isomerization" and "hydroforming" or "aromatization" and "cyclization" processes. Isomerization is the changing of one chemical compound to another having the same chemical composition and molecular weight but different properties, owing to a change in the structural relationships of the atoms of carbon and hydrogen in the molecule. The conversion of normal butane (C_4H_{10}) to isobutane is accomplished commercially by this catalytic process. The isobutane is then combined with butylene (C_4H_8) to form iso-octane (C_8H_{18}) for 100-octane aviation gasoline.

Hydroforming processes for converting straight-chain paraffin hydrocarbons to cyclic compounds of the aromatic series, such as toluene, have been applied to the production of this latter compound on a large scale. It is estimated that about 1,500,000 barrels of toluene from petroleum will be required annually for the production of TNT (trinitrotoluene) and other chemicals. This is in addition to about 700,000 barrels obtained as a byproduct in the coking of coal.[5]

In addition to these needs, the petroleum industry is called on to supply a large part of the butadiene required for the production of 800,000 tons annually of Buna-S type synthetic rubber. The available supply of butane will be hard-pressed to furnish this requirement, as well as that of aviation gasoline. Fortunately the development and installation (now in progress) of several new and more efficient catalytic cracking processes, especially the new "moving" or "fluid-flow" catalyst process, promise to improve both the quality and yield of gasoline from crude oil, so that no fear need be entertained of a shortage when these installations are completed. Some of these new refineries have produced as high as 70 percent gasoline from the stock treated.

Displacement of Coal by Fuel Oil

Since the earliest days of the petroleum industry, refining operations have been adjusted to the market demands for the lighter fractions. Before 1910, kerosine and afterward gasoline set the pace. The residual portions, almost half of the total crude, sought and found a receptive market as gas oil and fuel oil. The price of these oils, as of any other byproduct, was set by prevailing fuels.

Liquid fuel was tried on ships before the First World War, and by its close virtually all the navies were burning oil. The merchant marine followed the example of the navies, and the oil-fueled tonnage of the world rose from 18 percent in 1920 to 40 percent in 1930 and to 55 percent in 1939. Forty-five percent of the oil-fueled tonnage of 1939 consisted of Diesel-powered ships.

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[5] White, A. G., Hopkins, G. R., Breakey, H. A., and Coumbe, A. T., Crude Petroleum and Petroleum Products: Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, p. 56.

The railroads also have been increasingly large consumers of fuel oil. Diesel-motored trains and numerous switching locomotives were installed in the last decade.

Since 1923 the use of fuel oil has spread to various industries, especially for operations requiring flexibility of heating, accurate control of temperature, and freedom from ash. The changing distribution of fuel-oil consumption since 1923 is shown in table 1 and figure 3. The most important recent trend before we entered the war is the ever-accelerating gain of oil heating for homes, apartments, and office buildings. The sale of heating and range oils increased from 25 million barrels in 1926 to 168 million barrels in 1941. This quantity of oil is equivalent to 33 million tons or 70 percent of the 1941 production of anthracitic coal. In all its uses, the consumption of fuel oil alone in 1941 was equivalent to about 126 million tons of coal - slightly more than one-fifth of the total production of all ranks of coal for the same year.

RISE IN USE OF NATURAL GAS

Next to petroleum, the most striking development of our bountiful supply of fuel is the utilization of natural gas. Once the source of eternal flames of ancient worshippers of fire, natural gas is now a premier fuel supplied through thousands of miles of pipe to heat homes and cook meals in half the area of the United States. It generates power for pumping gas and oil in the producing fields, it furnishes carbon black for filler in automotive tires, and it is becoming an important raw material for new chemical products. A few deposits contain the noninflammable helium now indispensable for the blimps used in combatting the submarine menace along our Atlantic coast.

Although employed for lighting Fredonia, N. Y., as early as 1821, the use of natural gas was sporadic until reservoirs of gas were discovered in the search for oil. The first iron pipe line for natural gas - a 2-inch line, 5-1/2 miles long - was built in 1872 from the Newton well to Titusville, Pa.

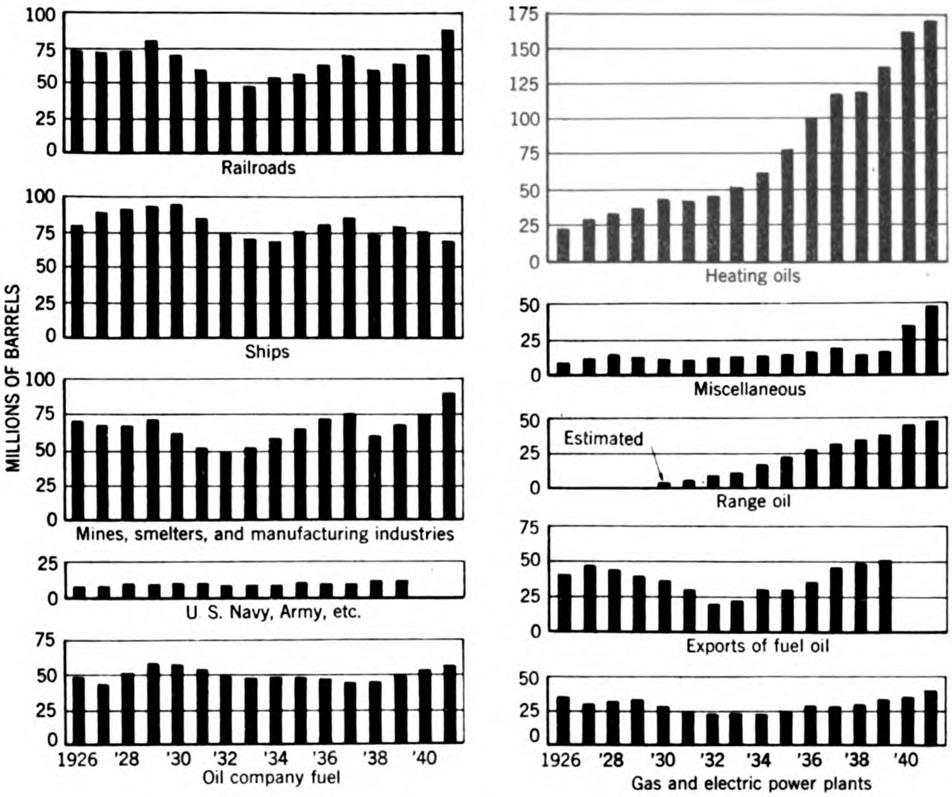

Figure 3.- Sales of gas oil and fuel oil, 1926-41, by uses.

Data from Crude Petroleum and Petroleum Products, Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, pp. 70-83.

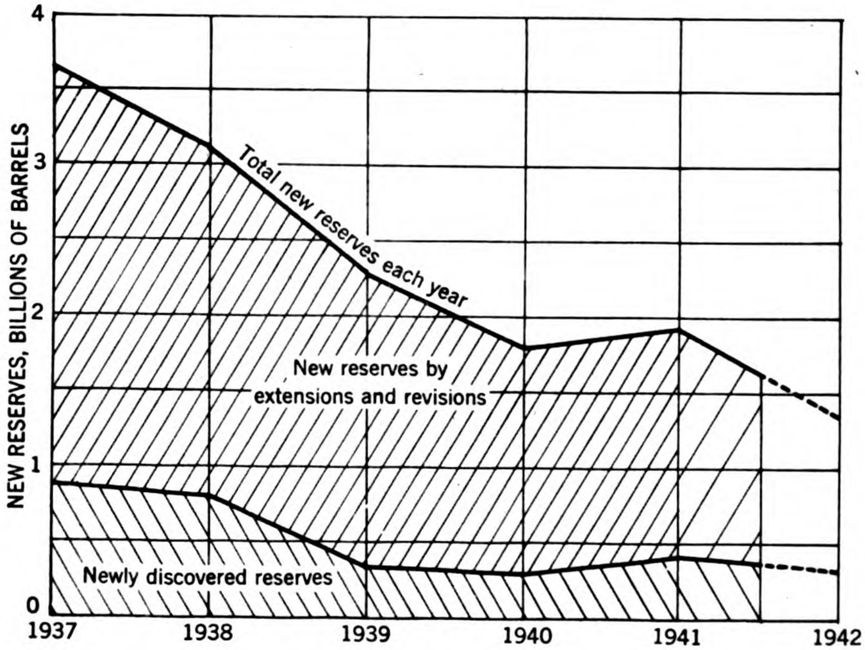

Figure 4.- Wildcat drilling and discovery of petroleum reserves, 1937-41.

From Lahee, F. H., Wildcat Drilling and Discovery of Petroleum Reserves: Bull. Am. Assoc. Petrol. Geol., vol. 26, June 1942, p. 980.

TABLE 1. - Sales of gas oil and fuel oil,[1] 1930-41, by uses, thousands of barrels of 42 gallons

(Data from Minerals Yearbook and Petroleum Economics Division, Bureau of Mines)

Uses	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941
Railroads	67,900	58,150	48,908	48,305	52,581	55,651	61,727	69,458	57,829	63,235	68,098	85,510
Ships	94,152	83,559	72,531	70,445	69,262	74,581	80,324	84,990	74,266	79,254	74,803	67,635
Gas and electric power plants	26,769	24,490	22,199	22,507	23,143	23,647	26,799	26,510	27,567	32,039	32,795	38,774
Mines, smelters, and manufacturing industries	60,762	51,236	48,500	51,500	56,942	63,576	71,326	74,798	60,038	67,043	73,940	88,387
Heating oils	43,279	40,578	44,264	50,140	60,822	76,853	99,257	116,617	118,323	136,232	160,379	167,514
Fuel oil (No. 1) sold as range oil	----	----	----	----	----	----	----	2,747	2,902	3,220	3,977	4,449
U. S. Navy, Army, etc.	8,681	9,203	7,968	8,000	7,914	10,428	9,241	9,135	11,756	12,472	17,183	----
Oil-company fuel	55,943	52,710	47,700	46,200	47,404	48,116	46,021	42,924	43,517	49,045	51,928	55,297
Miscellaneous uses	9,875	9,211	9,500	11,250	12,253	13,133	13,714	14,624	11,652	14,403	15,655	[2] 46,763
Total, United States	367,361	329,137	301,570	308,347	330,321	365,985	408,409	441,803	407,850	456,943	498,758	554,329
Exports and shipments	36,450	29,231	19,994	20,563	28,605	28,948	34,883	45,433	47,561	49,505	35,249	----
Total	403,811	358,368	321,564	328,910	358,926	394,933	443,292	487,236	455,411	506,448	534,007	----
Range oil	3,000	4,549	6,841	10,269	15,756	21,526	27,292	32,259	33,707	37,061	44,692	45,700

[1] Includes distillate fuel oil, residual fuel oil, and some crude oil burned as fuel.

[2] Includes all other uses.

Other wells and new discoveries followed, first in Pennsylvania, then in West Virginia, Ohio, Kentucky, Indiana, the midcontinent, and California. The natural gas of the Appalachian field was absorbed more quickly by the centralized industries and many homes of the East than in the sparsely populated Southwest, where later extensive reservoirs of oil and gas in Oklahoma, Louisiana, Texas, Arkansas, and Kansas were opened. Because of the association of gas with oil, the original waste of gas in these fields was enormous. Fortunately, the very magnitude of these fields convinced far-seeing industrialists that large investments in long-distance pipe lines to centers of consumption would be justified. Beginning in 1926, pipe lines were built, successively, to New Orleans, Memphis, St. Louis, Birmingham, and Atlanta. The largest proved reserves of natural gas in the United States are the Amarillo field in the Texas Panhandle and the more recently discovered Hugoton field in southwestern Kansas and northwestern Oklahoma. The proved reserves in these two fields are estimated to be about 30 trillion cubic feet - enough to insure 10 years of production at the present rate of consumption. Pipe lines from these fields supply not only the nearby States of the Middle West but extend to Denver, Omaha, Minneapolis, St. Paul, Chicago, and Detroit. In the Western States, natural gas from California supplies most of that State; natural gas is piped from Wyoming to Salt Lake City, Utah; and many of the cities of Montana are supplied from nearby fields. In 1941, the volume of natural gas marketed reached an all-time high of 2.8 trillion cubic feet, and this volume probably was exceeded in 1942. Actually, the total quantity of natural gas produced probably was some 4 trillion cubic feet. In 1940 the production and disposition of natural gas were estimated as follows:[6]

Estimated production.	Millions of cu. ft.
From gas wells	2,095,180
From oil wells	1,598,920
Total	3,694,100
Estimated disposition.	
Marketed production	2,660,222
Repressuring	362,916
Stored in ground	14,995
Losses and waste	655,967
Total	3,694,100

The 655 million cubic feet listed under "losses and waste" include residue gas blown to the air from natural-gasoline plants and transportation losses but do not include direct waste on producing properties, except where data are available. Although the waste of at least one-fifth, and probably much more, of the annual production of natural gas is less than before long-distance pipe lines were constructed, efforts should be continued to reduce this loss to a much smaller proportion of the total output. One practical method of utilizing excess gas incident to the production of oil is to pump it back into the oil strata to aid in the further discovery of oil. Such repressuring, and also the storage of natural gas in underground reservoirs for future use, have made considerable progress in the last 3 years.

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[6] Lott, F. S., and Hopkins, G. R., Natural Gas: Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, p. 5.

Natural Gasoline and Liquefied Petroleum Gases

About half of the natural gas produced in the United States comes to the surface in association with oil. Even the so-called "dry" gases contain appreciable quantities of propane, butane, pentane, and higher members of the paraffin series of hydrocarbons. From 0.5 to 10.0 gallons of gasoline and condensable hydrocarbons can be recovered from 1,000 cubic feet of "wet" gas by compression and refrigeration, or by absorption in oil or charcoal. Beginning in 1913, the recovery of natural gasoline has grown steadily to a total annual production in 1941 of 54 million barrels or about 10 percent of the total production of gasoline. The average yield was approximately 1 gallon per 1,000 cubic foot of natural gas treated.

In the early days of the industry the volatile propane, butane, and pentane fractions were allowed to evaporate into the atmosphere to obtain a stable product suitable for blending with refinery gasoline. This procedure not only wasted these fuels, but a considerable proportion of stable gasoline was lost. Beginning about 1924, the application of modern chemical engineering in the use of bubble-type absorbers and stills with efficient rectifying columns eliminated these losses. The volatile fractions were recovered and transported under pressure in tank cars and trucks for industrial fuel and in steel bottles to domestic consumers. From the modest figure of 223,000 gallons in 1922 the marketed production of these liquefied gases increased at an average rate of about 30 percent per year to 463 million gallons in 1941. Forty-eight percent of this fuel was supplied to domestic consumers who live beyond the reach of gas-distribution systems; 21 percent was used by industrial plants, 14 percent served as internal-combustion-engine fuel, and 10 percent was converted into chemical compounds.

The outbreak of the war brought vital new demands on these hydrocarbons, not only for supplying convenient cooking and heating fuel at many military camps, but also for use in war production plants and as raw materials for 100-octane aviation gasoline and synthetic rubber. By the removal of four hydrogen atoms, butane (C_4H_{10}) is converted to butadiene (C_4H_6), which comprises three-fourths of the raw material that is copolymerized to form Buna-S rubber. Butane also may be converted to isobutane and then combined with butylene for the production of iso-octane (C_8H_{18}) which is a high-octane blending agent in aviation gasoline. Propane, likewise, provides high-octane values after being chemically combined with benzol to from cumene (Isopropylbenzene, C_9H_{12})

It is evident that we are on the threshold of new developments of major significance in the future utilization of these hydrocarbons, which, but a few years ago, were wasted in amounts unbelievable from our present point of view.

COAL PRODUCTION AND UTILIZATION

Let us turn now to the changing use of coal - once our only mineral fuel - now supplying a little more than half of our energy consumption. I have traced the rise of petroleum and natural gas which, together, in 1941 provided 42 percent of the energy consumed. These fuels replaced coal in both domestic and commercial use. The fuel oil and gas oil used in 1941 were equivalent in heating value to 126 million tons of coal. Increased use of fuel oil is responsible for a large part of the decline in the use of anthracite for domestic heating, and together with natural gas has almost completely replaced the use of producer gas from coal in the United States. In the steel industry, surplus gas and tar from byproduct coke ovens have added their quota in replacing gas producers for heating open-hearth furnaces. In 1941 natural gas supplied 69 percent of the volume of gas and 79 percent of the energy sold in gaseous form to domestic and commercial consumers by public-utility gas companies.7/ In recent years, construction of coke ovens has been limited by the demand for coke rather than by the demand for gas.

Increase of Fuel Efficiency in the Use of Coal

Increased efficiency in the use of coal also has contributed in a marked degree to the decline in the consumption of coal. Since 1899 the average consumption of coal per kilowatt-hour of electrical energy in public-utility power stations has declined from 7.05 pounds to 1.34 pounds in 1941. Since the most efficient modern stations are producing 1 kilowatt-hour from 0.8 pound of coal, further decrease of the average may be expected as new equipment replaces the old. Other indicators of the effect of increasing fuel efficiency on the consumption of coal since 1919 are: Reductions in average consumption of locomotive fuel from 170 to 111 pounds (34.7 percent) per 1,000 gross ton-miles freight service; from 18.5 to 14.9 pounds (19.5 percent) per passenger-train car-mile; from 3,577 to 2,828 pounds (20.9 percent) of coking coal per gross ton of pig iron made; and from 3.2 to 1.3 pounds of coal (59.4 percent) per kilowatt-hour generated by public-utility power plants. These savings of coal, ranging from 20 to 60 percent, show what can be done by applying the results of fuel-efficiency research to the design and operation of fuel-using equipment. It is conservatively estimated that the extension of such work to all coal utilization could effect an annual saving of 5 percent of the coal consumption. At present, it would amount to 30 million tons a year - an important item in view of the scarcity of manpower and railroad cars.

7/ Corgan, J. A., Ridgway, R. H., and Coleman, A. V., Pennsylvania Anthracite: Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, p. 15.

Mechanical Mining and Preparation of Coal

In the commercial competition between coal on the one hand and petroleum and natural gas on the other, lower cost to consumers and availability at all times are the principal factors favoring the use of coal. Realizing this condition, the coal industry in recent years has given special attention to lowering the cost of production and improving the quality of its commodity. Improved machinery has been designed for cutting coal at the face and loading it mechanically into cars. Underground conveyors have been installed - in one instance, 4 miles long. The total percentage of bituminous coal and lignite mechanically loaded underground increased rapidly from 12 percent in 1935 to 27 percent in 1938 and to 35 percent in 1940. The general increase of mechanical mining operations and large-scale mechanical strip mining has made it possible for the coal industry to meet successfully the greatly increased demands of the war program, even though some 60,000 of the 450,000 bituminous-coal miners have left the mines because of the draft or to accept higher-paid jobs in war plants.

Reduction in the cost of mining coal has been followed on a lesser scale by improvement in the quality of coal. Washeries and cleaning plants have been installed at many mines for reducing ash and sulfur to the lowest practicable limits. About 15 percent of the coal produced in 1935 was washed or air-cleaned. This proportion increased to 18 percent in 1938 and to 22 percent in 1940. More progress should be made by the coal industry in including cleaning plants as essential parts of their mine installations. Uniformity of product is an important asset in holding a satisfied customer. A good preparation plant provides fuels of definite size gradation and constant ash and sulfur content.

Residential Stokers

To hold the house-heating trade coal producers, in cooperation with appliance manufacturers, have made considerable progress in developing improved automatic stokers that have much of the convenience of gas or oil burners at a lower cost for fuel. The sales of mechanical stokers for residental use have increased from 7,000 in 1932 to 76,000 in 1936 and to 179,000 in 1941.[8/]

Attention also has been given to the improvement of simple room heaters for burning bituminous coal without the production of smoke, and it is predicted that several new stoves of this type will be on the market after the war.

The treatment of coal with oil, to allay dust and to prevent difficulty in unloading cars due to freezing, had become so popular that the prohibition of this use of oil in 1942 created a real hardship for the coal industry. Solutions of hygroscopic salts combined with corrosion inhibitors continue to be available and are used for antidust treatment.

[8/] U. S. Department of Commerce, Bureau of the Census, Factory Sales of Mechanical Stokers: Current Statistical Service, February 3, 1943, p. 2.

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DISTRIBUTION OF ENERGY CONSUMPTION IN 1940

Having reviewed the changing conditions of fuel supply and demand during the last 30 years, let us consider the situation before the United States entered the present war. The distribution of energy consumption in 1940 - a year in which the total consumption of energy was almost as high as in 1929 - is given in tables 2, 3, and 4. In round numbers, residential, office, and public-building heating consumed 20 percent, transportation 30 percent, and public utilities, coke ovens, manufacturing and miscellaneous industrial uses 50 percent of our energy supply. Coal constituted 52 percent of the fuel for heating residential, office, and public buildings, 4 percent of the energy source for driving ships, 85 percent of the fuel used by railroads, and 70 percent of the fuel supplied to public utilities, coke ovens, and manufacturing and miscellaneous industrial plants; petroleum served as 60 percent of transportation fuel, including 100 percent of road-vehicle and airplane fuel, 96 percent of marine fuel, and 15 percent of railroad fuel; natural gas comprised 14 percent of the fuel used for heating residences, offices, and public buildings and 18 percent of the fuel used in manufacturing and miscellaneous industries. It is evident from this review that at present petroleum is the essential fuel for all transportation where internal-combustion engines are used as the source of motive power. This means most marine transportation and all road vehicles and airplanes. In a period of declining production of petroleum, such uses are likely to persist at the expense of other uses for petroleum, such as industrial and domestic heating. Let us consider, now, the national reserves of fuel as they appear in the light of present knowledge.

NATIONAL RESERVES OF FUEL

During 1938 the United States produced and consumed one-third of the world production of coal, two-thirds of the petroleum, and 95 percent of the natural gas. We have a little more than one-half (3.2 trillion tons of coal and lignite) of the world reserves of coal and probably a much smaller proportion of the total reserves of oil. More than three-fourths of the oil produced in all countries since the discovery well was drilled in 1859 has come from Americ wells.

TABLE 3. - Distribution of energy consumption from mineral fuels in 1940, in trillions of B.t.u.[1]

	Coal		Petroleum					
	Anthracite	Bituminous	Gasoline	Kerosine	Fuel and gas oil	Natural gas	Totals	Percentage of total energy consumption
Transportation	36	2,392	2,721	-	960	-	6,109	28
Railroads	36	2,366	6	-	408	-	2,816	13
Ships and boats	-	26	5	-	552	-	583	3
Road vehicles and airplanes	-	-	2,710	-	-	-	2,710	12
Public-utility power	62	1,326	-	-	102	183	1,673	8
Public-utility gas	5	182	-	-	96	-	283	1
Coke ovens	-	2,002	-	-	-	-	2,002	9
Manufacturing and miscellaneous	203	4,368	285	-	852	1,893	7,601	35
Residential, office, and public-building heating	967	1,118	-	380	984	579	4,028	19
Totals	1,273	11,388	3,006	380	2,994	2,655	21,696	100
Percentage of total energy, all fuels	6	52	14	2	14	12		100

[1] This table was computed by multiplying the weight or volume units of fuel given in table 2 by the appropriate conversion factors: Heating values used in conversion: 1 ton coal = 26 million B.t.u.; 1 bbl. gasoline = 5.1 million B.t.u.; 1 bbl. kerosine = 5.5 million B.t.u.; 1 bbl. fuel oil = 6.0 million B.t.u.; 1000 cu. ft. natural gas = 1 million B.t.u.

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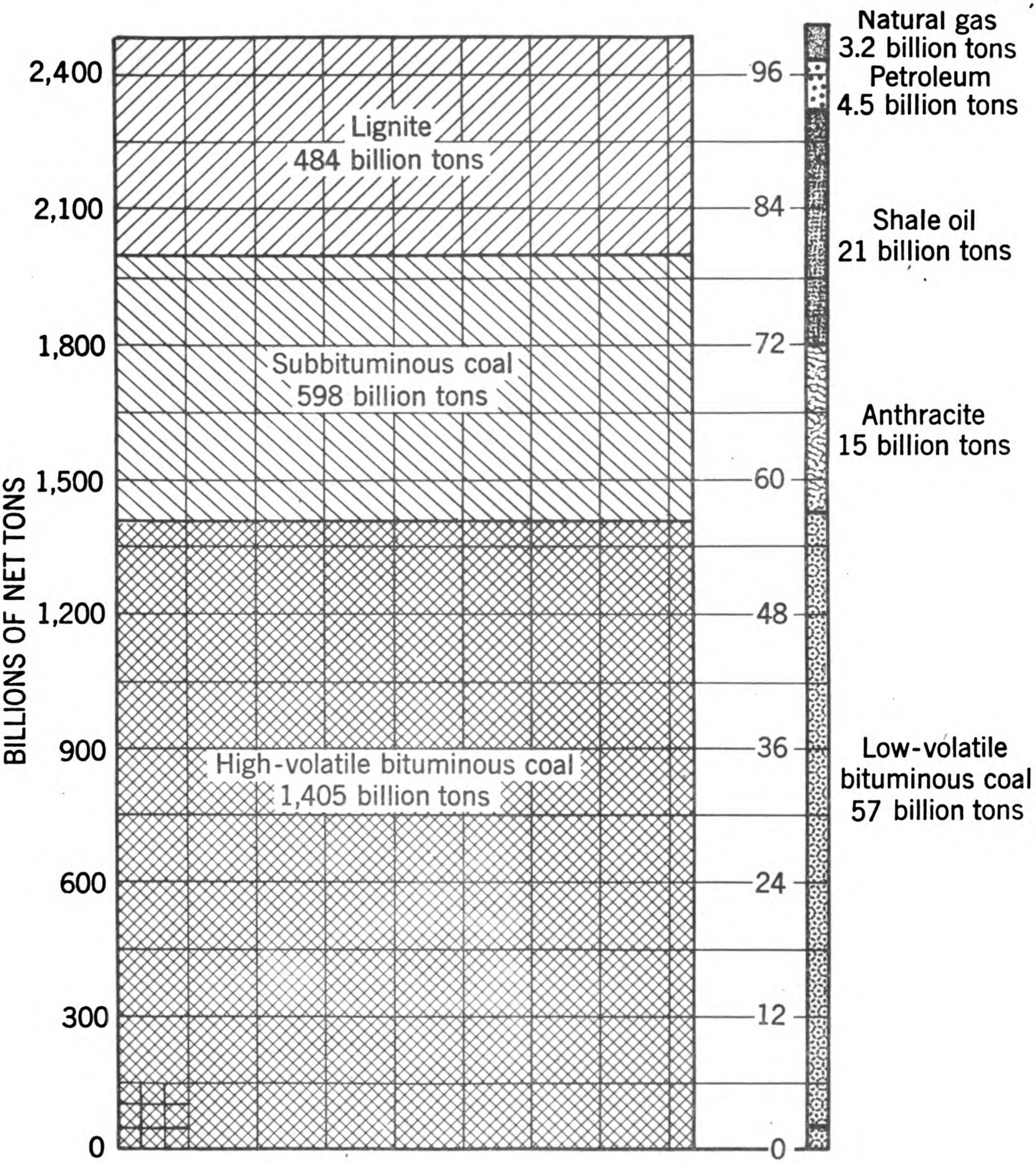

Figure 5.- Estimated mineral fuel resources of the United States as of January 1, 1942.

All fuels expressed in equivalent tons of bituminous coal of 13,000 B.t.u. per lb. calorific value. Medium-volatile bituminous coal is distributed between high- and low-volatile coal. (1 small square equals 2 billion tons.)

TABLE 4. - Energy supplied by the several mineral fuels for certain major uses in 1940, percent

Kind of fuel	Residential, office, and public-building heating	Public-utility power, gas, coke ovens, manufacturing and miscellaneous	Railroads	Ships	Road vehicles and airplanes	Total transportation
Coal	52	70	85	4	-	40
Petroleum	34	12	15	96	100	60
Natural gas	14	18	-	-	-	-
Total	100	100	100	100	100	100

Reliable estimates of the total national reserves of petroleum, unlike those of coal, cannot be made. We can deal only with the proved reserves. In 1934 the Geological Survey estimated the oil in the ground recoverable by the current methods of production to be 13 billion barrels. This reserve was increased rapidly in the next 4 years and reached 19.4 billion barrels in 1939. Since that date the development of proved reserves paced production until last year, when output exceeded discovery. The Committee on Petroleum Reserves of the American Petroleum Institute estimated the proved petroleum reserve to be 21.2 billion barrels on January 1, 1942 and 20.7 billion barrels on January 1, 1943.[9] As shown in figure 4, discoveries of new oil fields have been declining since 1937, and since 1939 they have amounted to less than half of the current production. Reserves during the last 5 years have been kept up by extensions and revisions of estimates of reserves in old fields rather than by the discovery of new fields. We cannot forecast future rates of discovery, but unless new oil fields approaching the magnitude of the East Texas field are found, it soon will be necessary to withdraw the use of oil for ordinary heating purposes that can be served by coal. Regardless of whether we are on the threshold of a permanent decline of petroleum production or whether new discoveries will postpone this period for several decades, it is evident that our reserves of gas and petroleum are small compared to reserves of coal. This comparison is illustrated graphically in figure 5, where the areas are drawn to scale and all the fuels are expressed in equivalent tons of bituminous coal of 13,000 B.t.u. per lb. calorific value.

The deposits of oil shale, largely in the Rocky Mountain States, are estimated to contain a potential supply of 92 billion barrels of crude oil - an amount sufficient to maintain the 1941 annual rate of oil production for 65 years.

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[9] Howard, W. V., Proven Reserves: Oil and Gas Jour., vol. 41, no. 38, January 28, 1943, p. 65.

TABLE 5. - Annual supply of energy from mineral fuels and water power in the United States,[1] trillions of B.t.u.

Year	1899[1]	1913[1]	1923[1]	1929[1]	1936[2]	1937[2]	1938[2]	1939[2]	1940[2]	1941[2]
Anthracite	1,643	2,490	2,539	2,008	1,485	1,410	1,255	1,400	1,400	1,478
Bituminous coal[3]	5,065	12,535	14,791	14,017	11,504	11,673	9,132	10,345	12,072	13,396
Domestic petroleum	342	1,491	4,394	6,044	6,598	7,675	7,286	7,590	8,119	8,425
Imported petroleum	0	102	492	474	194	165	158	199	256	(4)
Natural gas	240	626	1,082	2,062	2,330	2,588	2,468	2,663	2,860	2,978
Water power[5]	238	609	680	810	812	871	866	838	880	934
Total	7,528	17,853	23,978	25,415	22,923	24,382	21,165	23,035	25,587	[5]27,211

/ Tryon, F. G., Young, W. H., Mann, L., and Bradley, J. R., Coal: Bureau of Mines Minerals Yearbook 1936, p. 564.

/ Bituminous Coal and Lignite: Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, p. 12.

3/ Water power converted to fuel equivalent at the average prevailing efficiency of all central stations for the year in question, declining from 6.45 lb. per kw.-hr. in 1902 to 1.34 lb. in 1941. The following equivalents were used: 1899, 7.05; 1913, 4.14; 1923, 2.41; 1929, 1.69; 1936, 1.44; 1937, 1.42; 1938, 1.41; 1939, 1.39; 1940, 1.37; 1941, 1.34; The conversion factors for other fuels are: Anthracite, 13,600 B.t.u. per lb.; bituminous coal and lignite, 13,100 B.t.u. per lb.; petroleum, 6,000,000 B.t.u. per bbl.; natural gas, 1,075 B.t.u. per cu. ft.

/ Not available for publication.

/ Imported petroleum not included.

TABLE 6. - Percentage of total B.t.u. contributed by the several mineral fuels and water power in the United States

Year	1899 1/	1913 1/	1923 1/	1929 1/	1936 2/	1937 2/	1938 2/	1939 2/	1940 2/	1941 2/
Anthracite	21.8	13.9	10.6	7.9	6.5	5.8	5.9	6.1	5.5	5.5
Bituminous coal 3/	67.3	70.3	61.6	55.1	50.2	47.8	43.2	44.9	47.2	49.2
Domestic petroleum	4.5	8.3	18.3	23.8	28.8	31.5	34.4	32.9	31.7	31.0
Imported petroleum	.0	.6	2.1	1.9	.8	.7	.7	.9	1.0	(4)
Natural gas	3.2	3.5	4.5	8.1	10.2	10.6	11.7	11.6	11.2	10.9
Water power 5/	3.2	3.4	2.9	3.2	3.5	3.6	4.1	3.6	3.4	3.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1/ Tyron, F. G., Young, W. H., Mann, L., and Bradley, J. R., Coal: Bureau of Mines Minerals Yearbook 1936, p. 566. Recalculated on basis of prevailing fuel equivalent of water power.

2/ Bituminous Coal and Lignite: Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, p. 13.

3/ Includes lignite.

4/ Imported petroleum not included.

5/ Water power converted to fuel equipment at the average prevailing efficiency of all control stations for the year in question. See footnote 3/, table 5, for equivalents used.

The ultimate reserves of natural gas cannot be estimated, and geologists have not given as much attention to estimating the proved reserves as they have to petroleum. Ralph E. Davis, an authority on the production of natural gas, estimates the proved reserve as of January 1, 1942, to be 85 trillion cu. ft. At the 1941 rate of 2.77 trillion cu. ft. of production a year, this quantity would last 30 years. Here also, new sources will be discovered; and the life of the fields, no doubt, will be extended greatly as growing social control will prohibit waste and low-grade use of this ideal fuel.

The original reserves of coal and lignite are estimated to have been 3.2 trillion tons - enough to cover the entire State of Ohio (area, 41,000 square miles) to a depth of 76 feet. Not more than 2 percent of the original supply of bituminous coal and about 30 percent of the anthracite have been exhausted. At the 1941 rate of energy consumption, assuming that coal will carry the load after oil, gas, and oil shale are exhausted and allowing 30 percent for mining losses, coal would last 1,500 to 2,000 years. (See table 7).

However, there certainly will be an increase in energy demand; an increase at the rate of increase prevailing during the twenties would cut the period to some 500 years, and shortage of supply would be felt in the Appalachian field in 100 years. The superior coals of the eastern region comprise only one-seventh of the total reserves. About 40 percent, in terms of heating value, of the total reserve consists of subbituminous coal and lignite, situated in the western part of the country, far from present centers of population. Much of the reserve consists of relatively thin or inaccessible beds that are difficult and expensive to mine. Exhaustion of 30 percent of the anthracite reserve has increased the cost of mining considerably. The same situation will develop relatively soon with respect to the best bituminous beds, which permit low-cost mining.

INFLUENCE OF WAR ON DEMAND FOR FUELS

With the exception of motor gasoline, war conditions have increased greatly the demand for virtually all kinds of fuel. Liquid fuel is fundamental to modern warfare. Aviation and motor gasolines are required for airplanes, tanks, and motor vehicles; and fuel oil and Diesel oil are used for propelling ships and submarines. Two-thirds of the tonnage of all materials consumed in expeditionary forces, including their transportation and protection, is said to be petroleum.10/ Increasing quantities of bituminous coal and anthracite are needed, not only to serve the expanded industrial program for which coal normally is used but also to replace fuel oil in the Eastern States, New England, and the Pacific Northwest. Natural gas is being transmitted at maximum pipe-line capacity to an expanding group of domestic and industrial consumers and to a number of new war industries and military camps in the natural-gas regions.

10/ Cole, Wm. P., Jr., (retiring chairman, House Petroleum Subcommittee), Letter to President Roosevelt on Petroleum Under War Conditions: Congressional Record, vol. 88, October 22, 1942, pp. A4075-A4079.

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TABLE 7. - Estimated mineral-fuel reserves of the United States

Description	Original reserve	Reserve Jan. 1, 1942	Exhaustion, percent	Production 1941	Equivalent tons bituminous coal of 13,000 B.t.u. per lb. calorific value 1/		Recovery, percent	Life at 1941 rate of production, years 2/
					Reserve Jan. 1, 1942	Production 1941		
1	2	3	4	5	6	7	8	9
Anthracite...billions of net tons	3/ 22	4/ 15	32	5/ 0.056	15	0.055	6/ 65	177
Low-volatile bituminous coal..do. 7/	3/ 56	4/ 53	5	8/ .101	57	.109	9/ 70	366
High-volatile bituminous coal.do. 7/	3/ 1,379	4/ 1,353	1.9	8/ .398	1,405	.413	9/ 70	2,381
Subbituminous coal...........do.	3/ 819	4/ 818	.1	8/ .012	598	.009	70	-
Lignite......................do.	3/ 940	4/ 939	.1	10/ .003	484	.002	70	-
Total, all ranks of coal...do.	3,216	3,178	1.2	.570	2,559	.588	69	3,003

1/ Heating values used in conversion: Anthracite, 12,700 B.t.u. per lb.: low-volatile bituminous coal, 14,000 B.t.u. per lb.; high-volatile bituminous coal, 13,500 B.t.u. per lb.; subbituminous coal, 9,500 B.t.u. per lb.; lignite, 6,700 B.t.u. per lb.; crude petroleum, 6,000,000 B.t.u. per bbl.; natural gas, 1,000 B.t.u. per cu. ft.

2/ Years' life is computed by the following formula: $\frac{\text{column 6 x column 8}}{\text{100 x column 7}}$.

3/ Hendricks, T. A., Chapter I, Coal Reserves; Energy Resources and National Policy: Rept. of Energy Resources Committee to National Resources Committee, January 1939, pp. 281-286.

4/ Reserves as of January 1, 1942, were computed by deducting 153 percent of the total coal mined before this date to allow for the 34.7 percent of the coal in the ground that is not recovered in the prevailing mining practice.

5/ Corgan, J. A., Ridgway, R. H., and Coleman, A. V., Pennsylvania Anthracite: Bureau of Mines Minerals Yearbook 1941, 1942, p. 1.

6/ Report of U. S. Coal Commission, part II, 1925, p. 655. 7/ Includes some medium-volatile coal.

8/ Total production of low-volatile bituminous coal is estimated as 90 percent of the production of bituminous coal in Districts 1 and 7 of the Bituminous Coal Division. On this basis approximately 20 percent of the total production of bituminous coal of the United States is low-volatile coal, and the remainder is high-volatile plus subbituminous coal. The production of subbituminous coal is estimated from detailed county production reports of Montana, Wyoming, and Colorado. The production statistics are taken from the chapter on Bituminous Coal and Lignite, Bureau of Mines Minerals Yearbook for 1941.

9/ Report of U. S. Coal Commission, part III, 1925, p. 1857.

10/ Bituminous and Lignite Coal Tables, Bituminous Coal Division, Department of the Interior, January 1943, p. 100.

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TABLE 7. - Estimated mineral-fuel reserves of the United States - (Cont'd.)

Description	Original reserve	Reserve Jan. 1, 1942	Exhaustion, percent	Production 1941	Equivalent tons bituminous coal of 13,000 B.t.u. per lb. calorific value 1/		Recovery, percent	Life at 1941 rate of production, years 2/
					Reserve Jan. 1, 1942	Production 1941		
1	2	3	4	5	6	7	8	9
Petroleum, proved reserve........ ....billions of bbls.	11/45	12/20	56	13/1.404	4.5	0.324	14/100	14
Oil in oil shale..............do. 15/	92	92	0	0	21.0	.0	14/100	16/65
Natural gas, proved reserve...... ....trillions of cu. ft.	17/135	18/85	38	19/2.770	3.2	.107	14/100	30
Total, all fuels	-	-	-	-	2,588	1.019	69.3	1,760

11/ Proved reserve on January 1, 1942, plus production from 1859 to 1941, inclusive.

12/ Estimated by Committee on Petroleum Reserves of the American Petroleum Institute. White, A. G., Hopkins, G. R., Breakey, H. A., and Coumbe, A. T., Crude Petroleum and Petroleum Products: Bureau of Mines Minerals Yearbook 1941, 1942, pp. 7, 11.

13/ See footnote 8/.

14/ Reserves of petroleum, oil shale, and natural gas are based on oil and gas recoverable by present-day methods.

15/ Winchester, D. E., The Oil Possibilities of the Oil Shales of the United States: Federal Oil Conservation Board, Rept. II, January 1928, pp. 13-14.

16/ At 1941 rate of petroleum production.

17/ Proved reserve on January 1, 1942, plus marketed production from 1906 to 1941, inclusive. Total marketed production up to January 1, 1937, is given as 37.81 trillion cubic feet, by Ralph W. Richards, Chapter 3, Natural-Gas Reserves; Energy Resources and National Policy: Report of the National Resources Committee, January 1939, pp. 294-297. Marketed production from 1937 to 1941, inclusive, was 12.611 trillion cu. ft. F. S. Lott and G. R. Hopkins, Natural Gas: Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, p. 2. Marketed production up to January 1, 1941 is 50.42 trillion cu. ft.

18/ Davis, Ralph E., Natural Gas Supply of the United States: Interstate Oil Compact Quarterly Bull., vol. 1, October 1942, p. 24. Pub. and distributed by Interstate Oil Compact Commission, 437 State Capitol Building, Oklahoma City, Okla. See also Gas, vol. 18, No. 11, 1942, pp. 22-6; Oil and Gas Jour., vol. 41, No. 22, October 8, 1942, p. 37.

19/ Marketed production, Lott, F. S., and Hopkins, G. R., Natural Gas: Bureau of Mines Minerals Yearbook 1941 (preprint chapter), 1942, p. 1.

The most urgent of these demands have fallen on the petroleum industry. It has been obliged to expand greatly its facilities for the production of aviation lubricants, 100-octane gasoline, and toluene for explosives. The industry also is engaged on an intensive program of developing processes and building new plants for the manufacture of butadiene from petroleum and natural-gas products for the production of synthetic rubber.

The coal industry, with its ample reserves, has been supplementing petroleum and natural gas wherever possible. The anthracite operators of Pennsylvania are increasing their production schedules at the rate of 5 million tons a year to replace fuel oil with hard coal in the Eastern and New England States, where lack of adequate transportation facilities from the interior oil fields has interrupted the usual supply. Railroad transportation with energy derived from coal is replacing much of the motor-vehicle transportation that has been stopped to conserve rubber. Pulverized coal has been found to be a satisfactory and cheaper substitute for fuel oil in metallurgical heating furnaces. Many oil-to-coal conversions have been held up only because of shortage of equipment. Colloidal fuel -- a mixture of coal dust in oil -- may offer a partial substitution for those who cannot install coal-burning equipment. Several industrial experiments are in progress with this type of fuel.

The great expansion of the steel industry in connection with the war program has required a corresponding increase in the production of metallurgical coke. From 57 million tons of coke in 1940, production has increased to 65 million tons in 1941 and 70 million tons in 1942. It is estimated that 75 million tons will be required in 1943 and 79 million tons in 1944. Ten percent of the 1943 production will be beehive coke. Temporary resumption of beehive coking is justified by the comparatively low investment required to rehabilitate old beehive ovens; however, it is regrettable that the byproducts, which are especially useful in the war program, are lost. The average yield of such byproducts per ton of coal carbonized in the United States for 1940 is: Light oil, 3 gallons; tar, 9 gallons; ammonium sulfate, 22 pounds; and surplus gas, 6,800 cubic feet. The surplus gas not required to heat the coke ovens is used for heating furnaces in nearby steel plants or distributed in city gas lines. All of the byproducts are essential materials for manufacturing munitions or war equipment. The light oil contains benzol, toluol, and xylol. Benzol is our only source of styrene, which comprises 25 percent of the raw material that is polymerized to form synthetic rubber. Picric acid, used in explosives, and phenol, used in making bakelite and other plastics, also are made from benzol, as is cumene, a high-octane blending agent for aviation gasoline. Toluol and xylol are nitrated to make explosives for shells and mines.

Coal tar contains phenols, cresols, and higher-tar acids, which are in great demand by the rapidly growing plastics industury, and uses are found for all the pitch that can be made in the production of carbon electrodes for the expanding aluminum industry.

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Ammonium sulfate, normally used as a constituent of fertilizers, is required in tremendous amounts for the manufacture of explosives. In fact, much additional ammonia is made directly from the nitrogen in the air to supply the large quantities of explosives required in modern warfare. Here also coal plays an important role in the manufacture of hydrogen from water gas. One cubic foot of nitrogen is combined with 3 cubic foot of hydrogen to make ammonia. Ammonia is oxidized with air to make nitric acid, and nitric acid is used for making trinitrotoluene (TNT) and nitrocellulose (smokeless powder), two of the most important military explosives.

The response of the depressed anthracite industry to the war stimulus is exhibited in the rise of production from 51 million tons in 1940 to 56 million tons in 1941 and an estimated 60 million tons in 1942. It is believed that 65 million tons of anthracite will be required in 1943.

The upward trend in the production of bituminous coal and lignite, as influenced by the growth of defense and war industries, is evident in the growing production figures since 1939. From 461 million tons in 1940 production increased to 511 million tons in 1941 and to 580 million (estimated) tons in 1942. The Office of the Solid Fuels Coordinator for War estimates that 600 million tons of bituminous coal and lignite will be required in 1943.[11]

To achieve this record production of 665 million tons of all ranks of coal in 1943, in the face of growing wartime handicaps of lack of transportation, manpower, and new equipment, is a problem that calls for the best efforts of the mining and transportation industries. These are being given by the Government and industry, with the aid of the Solid Fuels Advisory War Council. In 1942, the shortages of coal were avoided for the most part by conducting a vigorous campaign to store coal during the normal periods of low consumption. Storage of bituminous coal in the hands of users and dealers reached an all-time record of 91 million tons on December 1, 1942. By storage in periods of lower consumption and by increase of working hours, it is hoped to maintain an adequate supply of coal and to avoid the difficulties of rationing and allocati that otherwise would become necessary.

With respect to the supply of petroleum fuels, the greatest difficulty has been caused by the enormous shift in means of transportation from the oil fields to the East coast, occasioned by loss of coastwise transportation in tankers. The railroads have done a magnificent job in meeting this emergency, and completion of the pipe lines now under construction will go far toward takin care of the most urgent needs.

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[11] Thomas, Thomas J., Coal Mining Has a Responsible Job in 1943! Min. Cong. Jour., vol. 29, no. 2, February 1943, p. 59.

The greatest concern for the future supply of oil is the continuing decline during the past 4 years in maintaining proved oil reserves by the discovery of new fields. This decline calls for a marked increase of exploration in order that the withdrawals from existing fields will not reach the point where the total recovery is diminished. To avoid this contingency, the Petroleum Administrator for War has recommended drilling 4,500 wildcat wells during the present year in comparison with 3,045 wells drilled in 1942.[12] If this enlarged exploration program is unsuccessful in restoring our former rate of finding new reserves of oil, the present trend of substituting coal for the industrial and domestic use of fuel oil is likely to continue, and ultimately supplementary supplies of automotive fuel from oil shale, coal, and vegetable products will be required. It is too early to make any definite predictions in this respect, but it is not too soon to give thoughtful consideration to the problem.

PROBABLE POSTWAR TRENDS IN FUELS SUPPLY AND DEMAND

Any evaluation of postwar trends of fuels supply and demand in the United States depends to a large degree on two unknown factors, first, the duration and victory of the war; and second, the discovery of new reserves of oil in the United States, in other countries of the Western Hemisphere, and in the Eastern Hemisphere. The Hon. William P. Cole, Jr., retiring chairman of the Petroleum Subcommittee of the Committee on Interstate and Foreign Commerce of the House of Representatives, in a letter to the President, stated that:

> There is a serious lack of understanding among both officials and laymen as to the real situation with respect to the supply of petroleum products for the conduct of the war. They have heard about the estimated 18 to 20 billions of barrels of crude petroleum remaining in the oil fields of this country and have the idea that this is a 13 or 14 years' supply at our present rate of consumption.
>
> There is no justification for such a belief. It will take many more than 14 years for this oil to be produced. Some of this oil will not be produced for 50 years.
>
> With our present transportation and present rate of discovery, showing any regard for conservation, we will be short of oil within 2 years.
>
> Another misconception widely held is that the productive capacity of the present crude oil-producing facilities of this country far exceed the quantity of crude oil currently being consumed.

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[12] DeGolyer, E., Petroleum Exploration and Development in Wartime. Oil and Gas Jour., vol. 41, February 25, 1943, p. 53.

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> It is true that if every oil well in the United States should be produced to capacity for a single day, the crude oil produced would exceed by several million barrels the amount which we use each day. But producing an oil well or an oil field at its full capacity results in such a waste of gas and such disruption of the ever-present underlying salt-water level as to result ultimately in a shameful and incurable waste. Petroleum engineers have proven that the wide-open flow of wells results in at least one-third less oil being ultimately recovered from the ground than when properly produced.

In closing his letter to the President, Judge Cole gave a brief comparision of recent discoveries of oil in the two great oil regions of the world—the Mississippi embayment-Caribbean oil region and the Mesopotamia-Caspian Sea oil region—and directed attention to the effect on our fortunes whether the United or Axis Nations win control of the oil resources of the Eastern Hemisphere. He went on to state that:

> Both regions have about the same amount of proven reserves of petroleum, but in prospective reserves, we are very inferior.
>
> During the last year we drilled 3,400 wildcat wells and discovered 400,000,000 barrels of new oil, about one-fourth of our consumption.
>
> In the region at the head of the Persian Gulf (only a portion of the main area), the last 100 wildcats have discovered 12,000,000,000 barrels of oil.
>
> The per-well ratio of discovery for wildcat wells is as 1,000 is to 1 as between the head of the Persian Gulf and the United States.
>
> These wells at the head of the Persian Gulf can be produced almost without cost, and the per ton of material per barrel of production is a tiny fraction of our own because the wells are all new, large, and flow under great pressure.

In 1936, Snider and Brooks[13] predicted the probability of a considerable shortage of domestic petroleum by 1945. They stated that:

> The prospect is apparently for a continuation or only a slight modification of the present situation until a shortage of domestic petroleum materializes. Domestic petroleum will then gradually

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[13] Snider, L. C., and Brooks, B. T., Probable Petroleum Shortage in the United States and Methods for Its Alleviation: Bull. Am. Assoc. Petrol. Geol., vol. 20, 1936, p. 49.

> be replaced by imports and substitutes in relative proportions and at price schedules not now predictable beyond a practicable certainty that the prices will be appreciably higher than the present ones.

In a recent article,[14] the same authorities state that:

> Unless adequate supplies of crude petroleum are made available, either by restoring imports or new discoveries (which does not seem probable), the refining industries as well as many established uses of petroleum products face radical and extensive changes.

It is evident from these statements that the postwar trend probably will be in the direction of greater conservation of our national petroleum resources and their more effective utilization. Wartime progress in the production of high-octane aviation gasoline probably will lead to its use in improved types of high-compression internal-combustion engines, which will increase greatly the mileage obtainable from a gallon of gasoline. In addition, the new facilities for the production of unprecedented quantities of the light metals aluminum and magnesium will make it possible to effect a considerable reduction in the weight of motor cars and trucks, which, in turn, will result in further reduction of fuel requirements. Thus it is possible that 50 percent greater mileage per gallon will be obtained in the use of these future motor cars anf fuels. Further economy in the use of liquid fuels also may be expected through additional development and wider use of Diesel engines.

After the war the petroleum industry, with the help of its large research organizations, should make renewed progress in recovering oil more completely from partly depleted reserves and in obtaining greater yields and improved quality of refined products from crude petroleum.

As prices of motor fuel rise owing to decreasing supplies, more attention will be given to secondary recovery from nearly exhausted fields and to the application of more expensive refining processes, such as pressure hydrogenation of low-grade crudes. It is probable also that the Fischer-Tropsch process will be applied to the conversion of natural gas to gasoline. Estimates[15] presented at recent House of Representatives subcommittee hearings gave the cost of such gasoline as 8.8 cents per gallon, using natural gas costing 3 to 5 cents per 1,000 cubic feet. It was thought that under these conditions this process would compete with gasoline from crude oil at $2.00 a barrel. Large reserves of natural gas are available for such conversion in parts of the United States remote from our present centers of population and industrial activity.

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[14] Brooks, B. T., and Snider, L. C., The Petroleum Shortage in the United States: Oil and Gas Jour., vol. 41, no. 37, January 21, 1943, p. 28.

[15] Farish, W. S., Appendix I, Hearing on Production of Gasoline from Coal, and Other Products: Subcommittee of the Committee on Mines and Mining, House of Representatives, 77th Congress, June 17, 18, and 25, and July 15, 1942, pp. 103-115.

When these and other technical developments and the importation of oil from foreign sources fail to meet the demand, prices probably will have advanced to the point where the production of automotive fuel from oil shale, coal, lignite, and renewable vegetable sources will be economically feasible. Most of our bituminous coal and lignite can be liquefied by the Bergius pressure-hydrogenation process, and all ranks and grades of coal can be converted to liquid fuel by way of water gas, as developed by Fischer and Tropsch. Both processes are in commercial use in Germany, where more than half of the supply of gasoline is thought to be made from bituminous and brown coal. Costs by these methods are estimated to be three to four times that of producing gasoline from petroleum in the United States.

Obviously, any decline in petroleum supply will increase the use of coal, except for additional natural gas made available by the construction of more long-distance pipe lines. Most of the industrial conversions from fuel oil to coal are likely to remain on coal after the war. Higher prices for fuel oil will discourage new installations using this fuel.

Use of distillate fuel oil for residential heating and range oil for cooking will continue even at higher prices than those prevailing today. However, much progress has been made in automatic stokers for solid fuels and the use of these should increase at more rapid rate when normal conditions are resumed. Ultimately the need for motor fuel will raise the price of residential fuel oil to the point where most house heaters will be converted to coal and products of coal.

Renewal of pre-war municipal activity in reduction of the smoke nuisance will require smokeless combustion of coal or the manufacture of smokeless fuels from coal. This requirement will provide an outlet for the increased quantities of coke that will be available from the new byproduct coke-oven capacity that was installed during the war to supply the increased needs for steel production.

In summarizing the relative position of the various fuels during the war, it is certain that each form of fuel - solid, liquid, and gaseous-- has had fundamental importance. The aggregate supply has equaled the demand, although there have been severe shortages in certain localities. Some of these will be alleviated by next winter, but others may develop. Relatively, the situation with respect to both oil and coal has been more satisfactory thus far than during the last war. Our greatest lesson is an appreciation of the great military value of petroleum products and the necessity of a national point of view in utilizing this much more limited national resource as compared with our abundant reserves of coal. Let us hope that we shall follow a sound, rational policy in making the best use of a rich heritage of mineral fuels.